WATER SPRAY SYSTEM DEVELOPMENT AND EVALUATION FOR ENHANCED POSTCRASH FIRE SURVIVABILITY AND IN-FLIGHT PROTECTION IN CARGO COMPARTMENTS

Timothy R. Marker
Constantine P. Sarkos
Richard G. Hill
Fire Safety Section
Federal Aviation Administration
William J. Hughes Technical Center
Building 287 AAR-422
Atlantic City International Airport, NJ 08405
USA

1. SUMMA^~Y

This paper describes full-scale fire tests conducted by the Federal Aviation Administration (FAA) to evaluate and optimize water spray systems in two specific aircraft fire safety applications. The first application was an onboard cabin water spray system designed to improve postcrash fire survivability. The goal is to suppress a severe cabin fire, initiated by a large external fuel fire, in order to improve the available time for passenger evacuation. The second application was a cargo compartment water spray system for the purpose of suppressing and controlling in-flight cargo/luggage fires. In this case, the water spray system must suppress and contain a worst-case, deep-seated fire for as long as 180 minutes, or until an airplane can be safely landed.

2. INTRODUCTION

Although aircraft crashes occur very infrequently, the life safety consequences of a postcrash fire are of great concern because of the potential involvment of large quantities of flamr^ıble jet fuel, the use of polmeric :naterials to line ..nd furnish the cabin, and the problems associated with the rapid evacuation of a large number of passengers from a confined environment.

The goal of enhanced postcrash fire survivability is twofold: (1) additional available time for passenger evacuation by reducing cabin fire hazards, and (2) greater evacuation rate of passengers. Improvements in postcrash fire safety attaining these goals have been achieved in recent years (Sarkos, 1989), including the installation of more fire resistant cabin materials, based on stringent fire test standards developed and adopted by FAA. The FAA has strived to develop further improvements in postcrash fire survivability in a joint program with the United Kingdom (U.K.) Civil Aviation Authority and Transport Canada to develop an on-board cabin water spray fire suppression system. The baseline water spray system was designed in the U.K. by Safety Aircraft and Vehicles Equipment, Ltd. (SAVE). It basically consisted of a large number of small nozzles, mounted throughout the ceiling, which discharged a fine water spray (mean droplet diameter of about 100 microns) throughout the length of the cabin for a period of 3 minutes (Whitfield, et al, 1988).

The test arrangement for the cabin water spray tests simulated a survivable aircraft crash involving fuselage exposure to an external fuel fire. The fire source was an 8-by-10 foot pan of burning jet fuel which had been shown previously to be representative of the thermal threat created by a large fuel spill fire. The discussion in this paper will be limited to a typical scenario comprised of a fuel fire adjacent to an opening (simulated rupture) in the test fuselage the size of Type A door (76 by 42 inches). A variable speed exhaust fan in the front of the fuselage created a draft inside the cabin, allowing the degree of fuel fire penetration through the hole and the resultant severity of the fire inside the cabin to be varied. Good control over the fuel fire conditions were maintained because the tests we.. conducted inside a building, assuring test repeatability. The 8-by-10 foot pan fire tests were conducted with both a narrow-body fuselage and a wide-body fuselage. The former is a surplus B-707 airplane while the latter is a 130-foot-long hybrid consisting of a 40-foot DC-10 section married to a 90-foot cylinder. Similar tests with a smaller fuel fire were conducted in a Metroliner commuter aircraft test article.

Aircraft cargo compartments are protected with Halon 1301 total flooding fire suppression systems. Since the production of halon ceased in developed countries on January 1, 1994, as specified by an international agreement called the Montreal Protocol, the future availability of halon for aviation is uncertain. Therefore, the FAA has a program to evaluate replacement and alternative agents/systems, such as water spray, in cargo compartment and other aircraft applications for the purpose of developing certification criteria for those agents deemed acceptable (FAA, 1993). A cargo compartment water spray system could also trade-off the weight penalty associated with a cabin water spray system.

The cargo compartment water spray tests were conducted in the lower forward compartment of the wide-body test article. The volume of the cargo compartment was 2300 cubic feet and the leakage rate was 85 cubic feet per minute, or one air change every 27 minutes.

3. EFFECTIVENESS OF CABIN CONTINUOUS WATER SPRAY SYSTEM

Narrow-Body Test Article. A plan view of the narrow-body test article is shown in figure 1, indicating the fuel pan location, continuous (SAVE) water spray system nozzle arrangement and location of instrumentation and cabin materials. The water spray system consisted of 120 nozzles which discharged 72 gallons of water over a period of 3 minutes. Instrumentation consisted of thermocouples, smoke meters, gas analyzers, gas sampling equipment, calorimeters, and photographic and video cameras. A 24-foot-long section of the test article, centered at the external fire pan, was outfitted with 5 rows of passenger seats, ceiling panels, stowage bins, sidewalls, and carpet. All materials were compliant with the current FAA fire test standards (Sarkos, 1989). A similar test setup was utilized in the wide body tests described later in the paper.

Initially, a zero ambient wind condition was simulated by not operating the exhaust fan. With the absence of flame penetration through the fuselage opening, the fire exposure of cabin materials was dominated by intense thermal radiation. The results of the zero wind tests, with and without water spray, are shown in figure 2. The shaded areas in this and subsequent figures show the range in measurements at a particular fuselage station. In all cases, the highest readings were at the highest locations, and the readings decreased the closer the measurement location was to the floor. Temperature was measured at 1-foot increments from a location 7 feet high (slightly below the ceiling) to a location 1 foot above the floor. Smoke was measured at three heights: 5 feet, 6 inches; 3 feet, 6 inches; and 1 foot, 6 inches. All gas measurements were at 5 feet, 6 inches and 3 feet, 6 inches.

Figure 2 exhibits a rapid rise in temperature and toxic gas production and a decrease in oxygen concentration at approximately 5 minutes in the test without water spray. This behavior indicates the development of a flashover condition at 5 minutes. However, when water spray was used, survivable conditions prevailed for the entire 7-minute test duration. The time interval of actual water spray discharge was from 15 seconds until approximately 195-200 seconds into the test. Therefore, in addition to the reduction in cabin fire hazards during the water spray discharge, there were notable improvements in the cabin environment after the discharge was completed.

Survival time was calculated from the measured hazards by employing a fractional effective dose (FED) model (Speitel, 1995). It assumes that the effect of heat and each toxic gas on incapacitation is additive and that the increased respiratory rate due to elevated carbon dioxide levels is manifested by enhanced uptake of other gases. The FED plot in figure 2 shows incapacitation occurred at 5 minutes without water spray discharge, corresponding to the time of flashover. Discharge of water spray prevented flashover within the 7-minute test duration and maintained a survivable environment within that increment (FED<0.1 at 7 minutes). Therefore, the increase in survivability provided by water spray discharge was much greater than 2 minutes.

A "moderate" wind scenario was devised, by operating the exhaust fan to induce fuel fire flame penetration through the fuselage opening, in order to create a more severe fire threat than imposed by the zero wind condition. Figure 3 shows the results of those test. The profiles are quite similar to the zero wind test (figure 2) but are transposed earlier in time by about 2 minutes. Flashover occurred between 150 and 180 seconds without water spray. With water spray, flashover occurred much later (about 300 seconds) and with less intensity (lower temperature rise and gas production). The FED plot shows that the increase in survival time was 215 seconds. Figure 3 also shows that water spray is highly effective in removing water soluble acid gases such as hydrogen fluoride.

The water spray system was also evaluated against a "high" wind scenario. In this case, the fuel fire flames penetrated across the ceiling practically to the opposite side of the cabin. The fire was so severe that it overwhelmed the water spray, and it became necessary to terminate the test after only 60 seconds. The high wind test further illustrated that the benefits of fire safety design improvements are highly dependent upon the fire scenario, and for some very severe scenarios it is virtually impossible to improve survivability by design changes.

Wide-Body Test Article. In the wide-body test article, the SAVE system consisted of 324 nozzles, arranged in 5 rows along the length of the fuselage. A quantity of 195 gallons of water was discharged over a period of 3 minutes. A "moderate" wind condition, causing fuel fire flame penetration through the fuselage opening, was utilized to evaluate the effectiveness of water spray in the wide-body test article. Figure 4 shows the result of those tests. As in the narrow-body tests, significant reduction in cabin temperatures and toxic gas levels were evidenced during the water spray test. Of some concern is the light transmission profiles reflecting the reduction in visibility due to smoke. For more than half the test duration, because the water spray tends to lower the ceiling smoke layer, there is a greater reduction in light transmission while the water is being discharged. Apparently, the amount of smoke particulate removal or "washing out" by the water spray is more than offset by the lowering of the smoke layer. Later, however, the reduction in light transmission with an unabated fire becomes more significant.

The FED curve indicates a loss of survivability at 215 seconds without the water spray system. Examination of the temperature and gas levels. particularly oxygen concentration (not shown), indicates the onset of flashover at about 210 seconds. With water spray, flashover was prevented over the 5-minute test duration and the cabin environment (away from the fire source) remained survivable. On the basis of the FED calculation, the improvement in survival time at the end of the test was 85 seconds, and would likely have been considerably longer, perhaps 2-3 minutes, had the test not been terminated.

4. OPTIMIZATION OF CABIN WATER SPRAY SYSTEM

Because of payload, weight penalty is an overriding consideration in aircraft design. The weight penalty associated with the SAVE system is somewhat excessive, if not prohibitive. The concept of a zoned system divides an airplane cabin into a series of water spray zones. Discharge of water within each zone is independent of the other zones and triggered by a sensor within the zone. In this matter the quantity of water discharged is dictated by the presence and spread of fire, eliminating the ineffectual and wasteful discharge of water away from the fire as in the SAVE system (Marker, 1991). A zoned system was designed, tested and optimized in the narrow body test article.

Each zone was 8 feet in cabin length. Four spray nozzles were mounted at the cabin periphery in each of the two boundary planes, with the spray discharge directed toward the center of the zone. Based on preliminary tests, a temperature of 300 degrees Farenheight (F) was selected to manually activate water discharge. The temperature was measured at the center of the zone about 6 inches below the ceiling . Three types of nozzles were evaluated; low, 0.23 gallons per minute (gpm) (SAVE nozzle); medium, 0.35 gpm; and high, 0.50 gpm. A more severe simulated wind condition than employed previously was used as the test condition.

The calculated FED profiles from the initial series of optimization tests are shown in figure 5. The SAVE water spray system, discharging 72 gallons of water, increased the survival time by 110 seconds. More importantly, the medium and high flow rate nozzles, discharging a total of only 24 gallons of water, increased the survival time beyond the SAVE system by about 55 seconds and 35 seconds, respectively. The improvement provided by the higher flow rate nozzles is apparently due to the application of larger quantities of water where it is needed most -- in the immediate fire area. An interesting result is that the medium flow rate nozzles provided more protection than the high flow rate nozzles. A possible explanation is that the discharge time was longer with the medium flow rate nozzles; i.e., 180 seconds versus 140 seconds.

In an attempt to optimize the zoned system, 9 zoned water spray tests were conducted, employing 4 water quantities and 3 nozzle flow rates. The results are summarized in figure 6 in terms of the additional available escape time beyond the baseline test without water discharge. The results of the SAVE test are also shown (108 seconds additional escape time). Each of the zoned tests provided a significant improvement in the additional escape time, which was greater than the improvement with the SAVE system in 5 of the 9 cases. Even with only 4 gallons of water, the zoned system was effective, increasing the available escape time by 53 seconds. The optimal nozzle discharge rate was 0.35 gpm.

In order to optimize the water quantity, the efficiency of a water spray system was defined as the ratio of the additional available escape time (seconds) to the quantity of water discharged (gallons), or seconds per gallons (SPG). Figure 7 compares SPG for the various water spray configurations on the basis of nozzle flow rate. It is evident that the most efficient or optimum zoned system utilized a medium flow rate nozzle (0.35 gpm) and a water quantity of 8 gallons. The optimum zoned water spray system (SPG = 20.4) was a factor of 13.6 more efficient than the continuous waters spray system (SPG = 1.5). It is significant that as much as 20 seconds of additional available escape time per gallon of water discharged may be achieved by a water spray system, operating effectively in a postcrash fire environment, where each second of available escape time is critical.

Improved visibility is another advantage of a zoned water spray system since continuously discharging water throughout the airplane tends to lower the ceiling smoke layer. With the zoned system the disruption of the smoke layer is primarily confined to the spray zones. Visibility during the zoned system tests improved by approximately 40-50 seconds compared to the SAVE system test (figure 8).

5. EFFECTIVENESS OF ZONED CABIN WATER SPRAY SYSTEM

Wide-Body Test Article. The effectiveness of a zoned water spray system was examined in the wide-body test article. The placement of nozzles was similar to the narrow-body arrangement with two exceptions. First, there were six nozzles in each of the two boundary planes. Second, for some tests a half-zoned geometry was used; i.e., the zone extended to the cabin symmetry plane rather than across the full cabin width. Another variation in some tests was the spray discharge activation temperature. As in the narrow-body tests, initial activation of spray discharge was set at 300 degrees F; however, subsequent zone activation's were delayed until the temperature reached 500 degrees F. This was done with the aim of conserving water for application in the initial zone where the fire intensity was greatest. The total quantity of water was only 21 gallons (vs. 195 gallons with the SAVE system). This was calculated by scaling to the optimum zone system and SAVE system water quantities in the narrow-body test article.

The calculated FED profiles are shown in figure 9. As in the narrow-body test article, the zoned water spray configurations provided a significant increase in survival time, ranging form 86 to 103 seconds under the conditions tested. Again, the medium flow rate nozzle (0.35 gpm) was more effective than the high flow rate nozzle (0.50 gpm), although by a relatively small amount (10 seconds). Small improvements are also seen from split zoning and elevation of discharge activation temperature in secondary zones (7 seconds).

Commuter Test Article. Currently, small commuter aircraft (19 seats or less) are exempt from the stringent FAA regulations that require seat cushion fire blocking layers and low heat smoke release panels in large transport aircraft. To determine potential improvements in postcrash fire survivability from usage of more fire resistant materials in commuter aircraft, and from a zoned water spray system, a series of full-scale tests were conducted in a Metroliner fuselage.

The fire scenario setup for the commuter test article was similar to that used in the large transport test articles, except on a reduced scale; e.g., 4-by-5-foot pan fire adjacent to 20-by-26-inch initial fuselage opening. The water spray system was comprised of 100 inch long zones, with each zone containing six nozzles. Only 5 gallons of water was discharged.

Figure 10 presents the survival time improvements resulting from fire blocked seats, improved panels and a water spray system. Each fire safety design improvement created finite survival gains. By far the largest increase in survival time was furnished by the water spray system - over 3 minutes. It was also shown in other tests that this incremental improvement would also be attained with less fire resistant materials. It is interesting that the survival time improvement for seat fire blocking layers, 45 seconds, is within the range measured previously in large transport full-scale fire tests (Sarkos, 1989).

6. EVALUATION OF CARGO COMPARTMENT WATER SPRAYS

An in-flight cargo fire presents a totally different fire threat than a postcrash cabin fire. The latter is an intense, open fire which must be suppressed for several minutes in order to enable passengers to escape. A cargo fire, however, may be a deep-seated fire, potentially involving a wide variety of cargo and baggage materials, which must be suppressed and contained within the confines of the cargo compartment. The period of protection must allow the airplane to be safely landed, which in some cases may be as long as 180 minutes.

The cargo compartment water spray tests conducted to date represent a worst case scenario. Since it is expected that water spray will effectively extinguish or suppress a fire originating in bulk-loaded cargo, testing has focused on water spray protection against fires in cargo containers. The test arrangement is shown in figure 11. It would appear that a containerized cargo fire presents greater discharge obstructions and less opportunity for soaking of cargo materials than a bulk-loaded cargo fire (individually loaded luggage and/or cargo). A standard fire load, consisting of cardboard boxes filled with shredded paper at a packing density of 2.5 pounds per cubic foot, was employed in all the tests. An unsuppressed fire burns out of the container through the polycarbonate walls. Aircraft Halon 1301 systems are designed to maintain an inerting concentration of Halon 1301 (>3%) throughout the period of protection, in effect, suppressing a deep-seated fire by preventing the occurrence of open flaming.

Two types of nozzles were evaluated in a zoned water spray configuration - high pressure and dual fluid. The high pressure nozzle produced a water fog at a flow rate of .027 liters/minute; the dual fluid nozzle discharged water mist at 2.5 liters/minute. Since water did not remain suspended in air for any appreciable time with either system, it was necessary to control the discharge of water based on temperature measurements taken within each zone.

The dual fluid nozzle water spray system was evaluated initially. A series of eight tests were conducted, varying the discharge activation temperature (200-300°F), deactivation temperature (150-290°F), and/or spray duration (6-10 seconds). The dual fluid nozzle system was effective in controlling the cargo fire, but the required quantity of water was excessive, ranging from 80 to 110 gallons, and showed little sensitivity to the parameters studied.

The initial tests with a high pressure spray system exhibited some reduction in the required quantity of water (minimum of 65 gallons). However, in order to be a candidate replacement for a Halon 1301 system, the water usage should be in the 10 to 20 gallon range. Therefore, the nozzle arrangement was modified by incorporating nozzles which sprayed directly downward in the space between the containers, in addition to the previous arrangement of nozzles which sprayed horizontally at the ceiling. Figure 12 shows this nozzle arrangement. Also shown is the cargo container fire configuration employed throughout the test program. As shown in Figure 12, the fire origin was in the lower corner container (the adjacent "blank" containers provided discharge obstructions). There were a total of eight spray zones, although only the single zone in which the fire was started activated in all of the tests. The fire zone discharged water at a rate of 1.0 gallon per minute (minimum flow rate required to suppress the fire).

A typical water spray test with the high pressure system is shown in figure 13. A 200°F activation temperature, 20 second spray duration and 10 second scan rate was employed during the test. The ceiling temperature measured above the cargo container was well below the safe level. Also, the oxygen concentration profile demonstrates that the fire was controlled by water spray (versus oxygen starvation). The quantity of water used, 41.3 gallons, demonstrated that the downward spraying nozzles significantly reduced water usage (65 gallons was the minimum quantity when only horizontal spray nozzles were employed). Moreover, in subsequent cargo container fire tests, by modifying certain spray parameters, the fire was controlled for 90 minutes by utilizing only 31.0, 34.4 and 31.6 gallons of water.

In order to evaluate the effectiveness of the spray system during a simulated bulk loaded cargo fire, 56 shredded paper filled boxes were arranged in two tiers of 7 boxes. A second water spray zone with a high concentration of downward spraying nozzles was added because the floor area of the bulk loaded cargo occupied two zones. The flowrate in each of these zones remained at 1.0 gallons per minute (identical to the container test which needed the least amount of water). During the first test, the spray was activated when the ceiling temperature reached 250°F, which allowed temperature excursions within the compartment to reach unacceptable levels (300°F to 800°F). Because the high activation temperature allowed the fire to grow sizably before allowing the system to gain control, an excessive 42 gallons of water was used. The next test used a 150°F activation temperature, which produced noticeably superior results in terms of both the temperatures observed and the amount of water required (24.8 gallons).

7. SUMMARY OF RESULTS

Full-scale tests demonstrated that an on-board cabin water spray system provided significant increases in survival time in all transport aircraft sizes during a postcrash fire. The main benefits of water spray were to delay the onset of flashover, reduce cabin air temperatures, and remove water-soluble toxic gases. Moreover, a zoned water spray system, utilizing relatively small quantities of water, increased the survival time and improved visibility when compared to a system that continuously discharged water throughout the cabin. Enhancement in survivability by zoning was attributed to concentrating the discharge of water to those cabin areas where the fire originated and spread, and to reducing the lowering of the smoke layer caused by water discharge. Full-scale tests also demonstrated that a cargo compartment zoned water spray system, employing either dual fluid or high pressure nozzles, effectively controlled a deep-seated in-flight fire, originating inside a cargo container, for a period of 90 minutes. Significant reduction in water quantities were attained by altering the nozzle arrangement and optimizing certain discharge parameters, such as zone spray activation temperature.

8. THE FUTURE OF AIRCRAFT WATER SPRAY SYSTEMS

The full-scale cabin fire tests described in this paper was part of a broad multi-national program, conducted primarily by FAA and CAA, to determine the feasibility and practicality of an onboard cabin water spray system for enhanced postcrash fire survivability. Various tests and studies were conducted to address the following issues: system effectiveness, system optimization, physiological hazards and other human factors, safety benefit analysis, manufacturer's disbenefits studies, airworthiness requirements and cost analysis (CAA, 1993). It was essentially determined that a zoned cabin water spray system is effective, safe and practical (some protective measures may be needed to tolerate an inadvertent discharge). These findings led to consideration of the of the development and evaluation of a prototype water spray system in an operational aircraft. Further development of a cabin water spray system, however, was discontinued after a cost/benefit analysis determined the high costs associated with life saving potential, approximately $20-30 million per life saved (CAA, 1993).

An aircraft cabin water spray system may still be a viable concept. Although the average benefit based on an analysis of past accidents and factoring in the impact of regulatory fire safety improvements is relatively small, there is the potential for alleviating a major loss of life in a single accident. The potential benefit may be even more pronounced in future, high capacity double-decked transports. Most important, however, is the potential significant reduction in cabin system cost if water spray were also incorporated as a halon alternative fire suppression agent in cargo compartments. It is conceivable that the quantity of water required to suppress a cargo compartment fire will also provide adequate capacity to supply a zoned, cabin water spray system. Utilization of potable water offers added protection and cost reduction depending on the fire scenario, flight type (over land vs. over water), etc.

Initially, aircraft manufacturers and airlines generally favored a gaseous halon replacement agent in cargo compartments, primarily because gases are "clean" and would require virtually no cleanup in the event of an accidental discharge. However, currently available halon replacement gaseous agents have one or more of the following disadvantages: additional weight and volume, greater toxicity, unknown future environmental restrictions, and higher cost. Obviously, toxicity, environmental concerns and cost (agent) are not concerns with water. Freezing is an issue that needs to be addressed. Further reduction in the quantity of water required to suppress a cargo fire may be possible because of the many options offered by zoned water spray. Water spray in aircraft cargo compartment fire suppression systems is a halon replacement option that exhibits more promise than envisioned several years ago.

REFERENCES

CAA, 1993, "International Cabin Water Spray Research Management Group: Conclusions of Research Programme", CAA Paper 93012, Civil Aviation Authority

FAA, 1993, "Halon Replacement Performance Testing", Public Notice 93-1, Federal Register, Vol. 58, No. 115, pp. 33477-33481.

Marker, T.R., 1991, "On-Board Cabin Water Spray System Under Various Discharge Configurations", Report DOT/FAA/CT-TN91/42, Federal Aviation Administration.

Sarkos, C.P., 1989, "Development of Improved Fire Safety Standards Adopted by the Federal Administration", AGARD-CPP-467, Propulsion and Energetics Panel 73rd Symposium on Aircraft Fire Safety, Sintra, Portugal, May 22-26, 1989.

Speitel, L.C., 1995, "Toxicity Assessment of Combustion Gases and Development of a Survival Model", Report DOT/FAA/AR-95/5, Federal Aviation Administration.

Whitfield, R.T., Whitfield, Q.A., and Steel, J., 1988, "Aircraft Cabin Fire Suppression by Means of an Interior Water Spray System", CAA Paper 88014, Civil Aviation Authority.

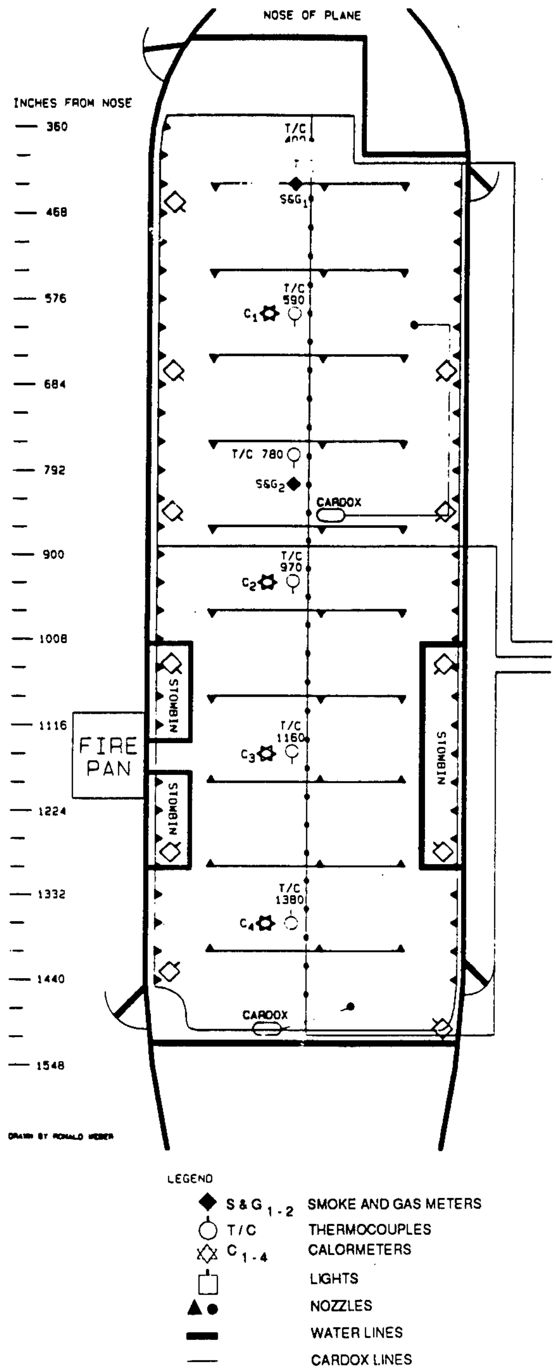

FIGURE 1. NARROW CABIN BODY TEST SETUP, SAVE SYSTEM

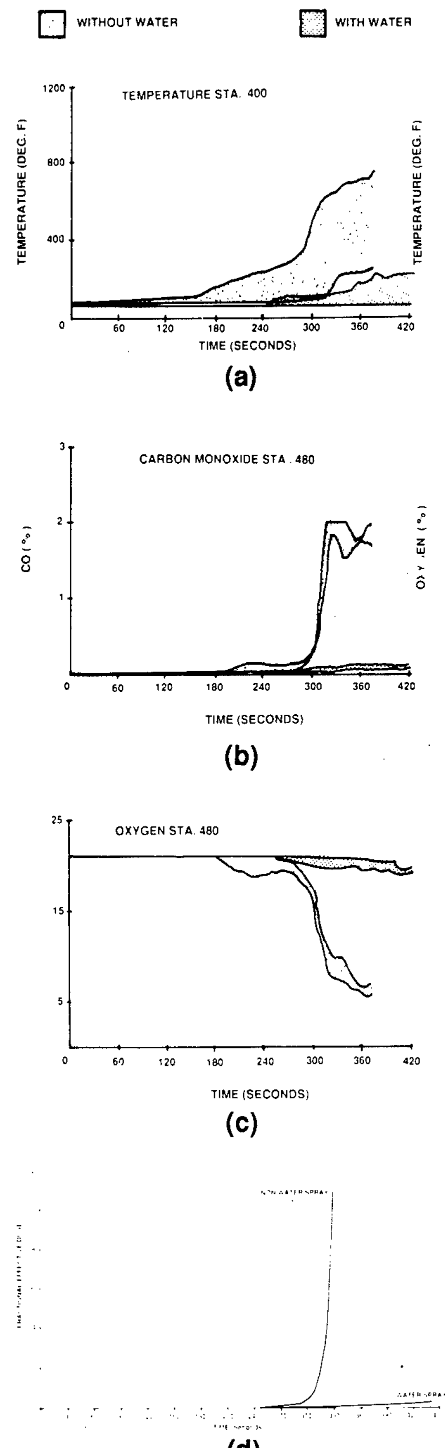

FIGURE 2. NARROW CABIN BODY RESULTS/SAVE SYSTEM/ZERO WIND

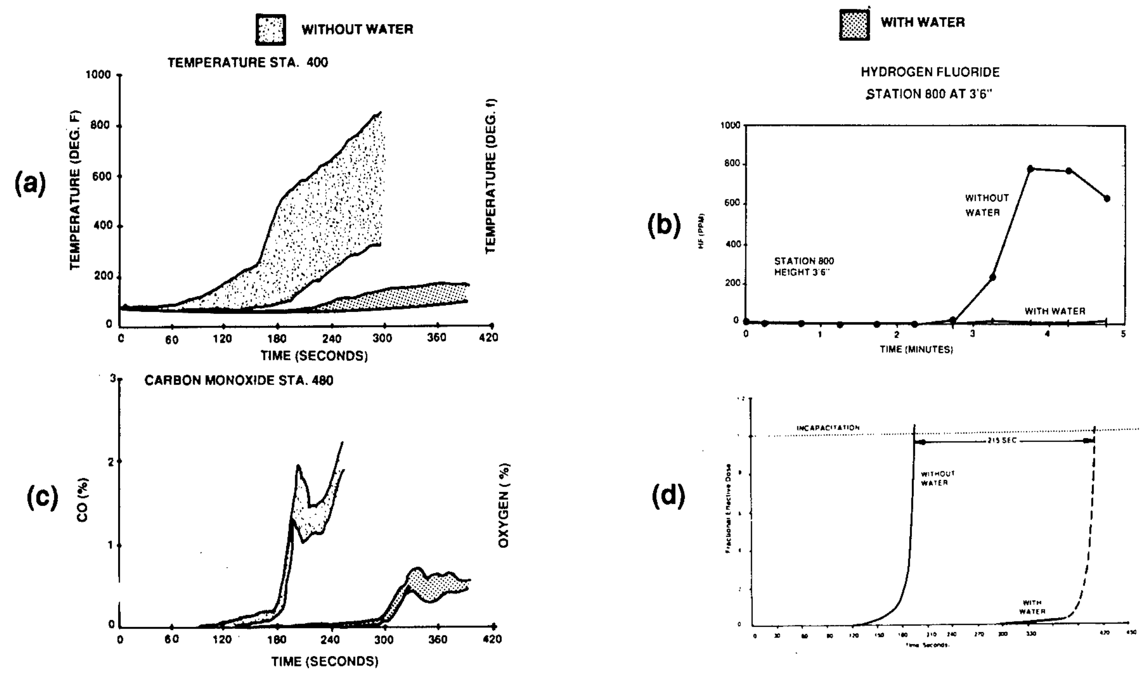

FIGURE 3. NARROW CABIN BODY RESULTS/SAVE SYSTEM/MODERATE WIND

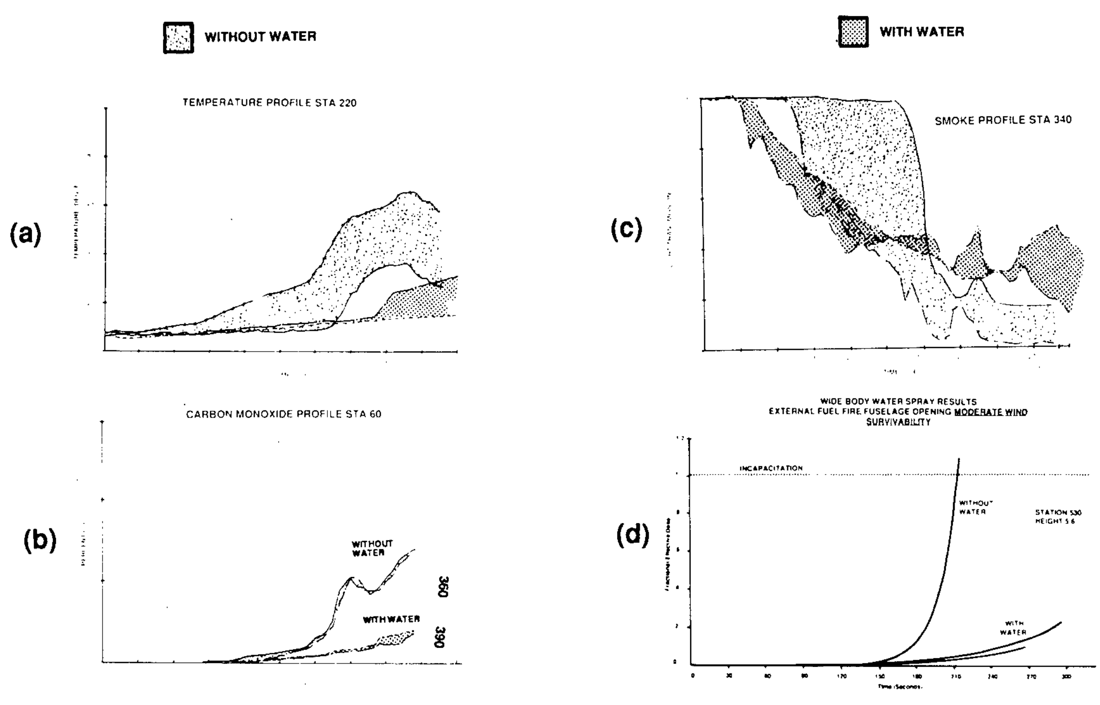

FIGURE 4. WIDE CABIN BODY RESULTS/SAVE SYSTEM/MODERATE WIND

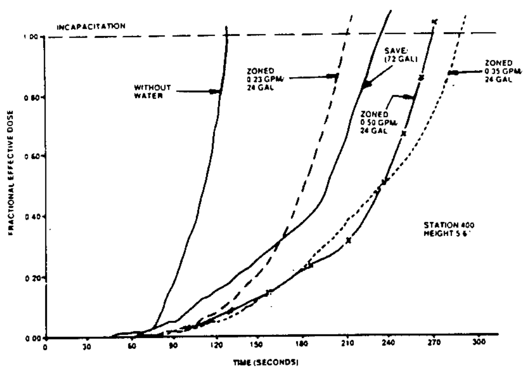

FIGURE 5. CABIN ZONED SYSTEM SURVIVAL TIME IMPROVEMENT, 24 GALLONS

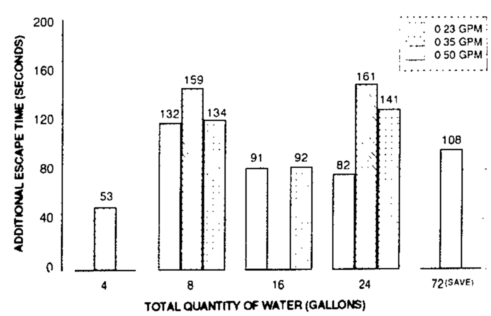

FIGURE 6. CABIN ZONED WATER SPRAY TEST RESULTS ADDITIONAL ESCAPE TIME

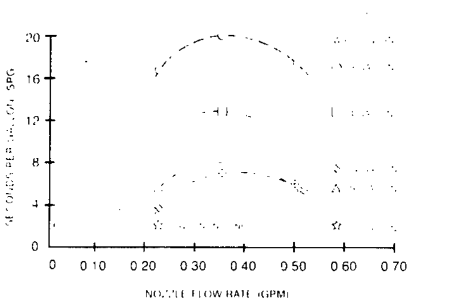

FIGURE 7. CABIN ZONED WATER SPRAY OPTIMIZATION TEST RESULTS

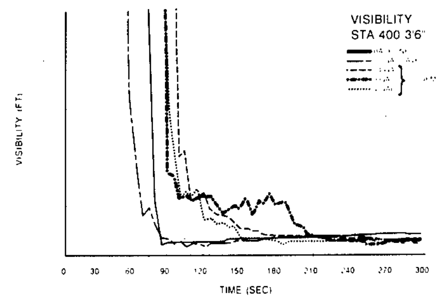

FIGURE 8. CABIN ZONED SYSTEM VISIBILITY . IMPROVEMENT

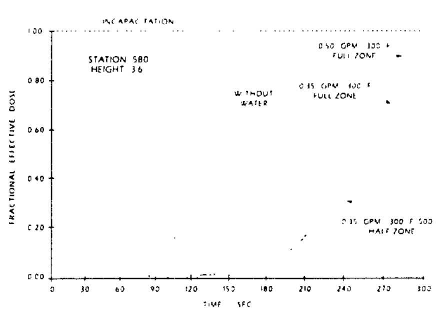

FIGURE 9. WIDE-BODY CABIN ZONED SYSTEM SURVIVAL TIME IMPROVEMENT

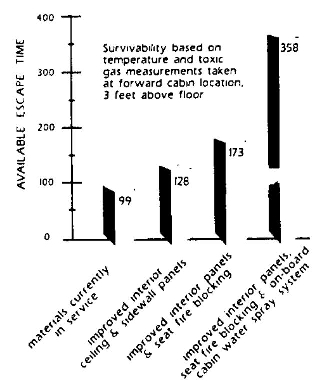

FIGURE 10. SURVIVABILITY IMPROVEMENTS IN COMMUTER TEST ARTICLE

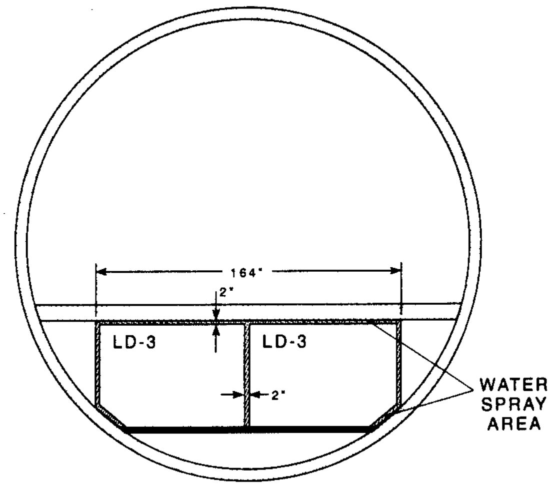

FIGURE 11. DC-10 CARGO COMPARTMENT CROSS SECTION

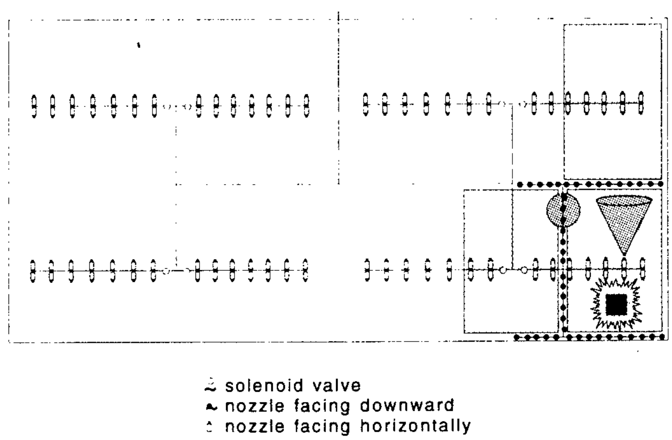

FIGURE 12. CARGO COMPARTMENT HIGH PRESSURE SPRAY SYSTEM

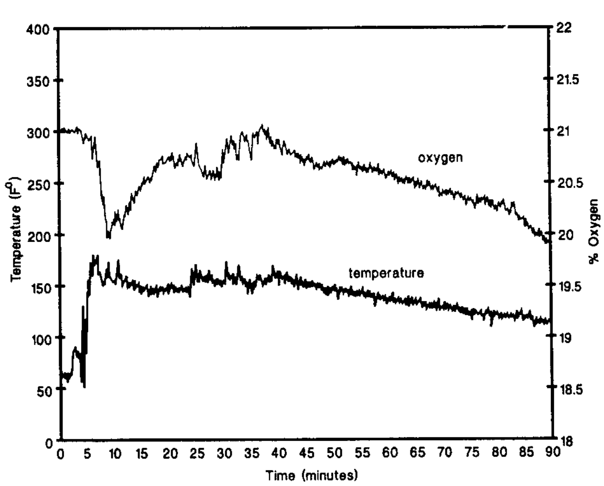

FIGURE 13. HIGH PRESSURE CARGO COMPARTMENT SYSTEM OXYGEN AND TEMPERATURE PROFILES

DISCUSSION - PAPER NO. 12

A. Mulder (Comment & Questions)

Comment: Very worthwhile research.

Questions:

1) Is there any knowledge about the difference in hazards between inhaling smoke, and smoke mixed with water mist?

2) With respect to Water Spray Systems in cargo compartment, are the so-called 'shaded areas' not a problem?

C.P. Sarkos - Author (Response)

1) What is most important is a comparison of the hazards at a given location and point in time with water spray and without water spray. Measurements during full-scale fire tests with water spray show significantly lower temperatures and toxic gas concentrations than without water spray. Also, the occurrence of flashover is delayed significantly. Similarly, in tests sponsored by the CAA, the collection of particles of various sizes that could be ingested showed lower levels of harmful deposits when water spray was used.

2) FAA cargo compartment fire tests have focused on the 'shaded area' created by a cargo container fire. Until the fire burns out of the container, any water spray discharge will be shielded from the fire. By using a ceiling temperature sensor, the fire could be controlled for 90 minutes by discharging water for 20 seconds if the temperature exceeded 200°F (10-second interrogation time).

N.J. Povey (Comment)

Additional comment to previous questions and answers. The CAA, as part of the joint FAA/CAA/TCCA programme - conducted a study (performed by Dr. David Purser - to investigate the risk posed by respirable water droplets (reported in CAA Paper 93009). Conclusion was that there was no additional risk. The benefit of water in stopping the production of toxic gases far exceeded any additional risk of respirable droplets.

H. Schmidt Question)

Did you investigate the influence of droplet size or droplet size distribution to extinguishing efficiency?

C.P. Sarkos - Author (Response)

We did not investigate the variation of droplet size to determine its effect on extinguishment efficiency. The cabin water spray system employed a mean droplet diameter of about 100μ. One concern for the cabin system was not to employ droplet sizes in the 20-30μ range which might be respirable. Smaller droplet sizes were used in the cargo system with the hope that a total flooding behaviour would result and the droplets would remain suspended for long periods of time.

W.B. de Wolf (Question)

1) Could you comment on the cost/benefit aspect of water spray systems based on the present technical status?

2) Could you also comment on possible patent issues?

R.G. Hill - Author (Response)

1) Cabin water mist systems have not been shown to be cost beneficial at present. However, if a cargo water mist system is shown to be acceptable as a Halon replacement, the cost of additional cabin protection may become cost beneficial.

2) Although some components specific to water mist systems may be patented, the concept is not.